Evaluation of an Involute Skimmer Design for Use With Small-Diameter Cyclones

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Evaluation of an Involute Skimmer Design for Use With Small-Diameter Cyclones

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ABSTRACT

Involute skimmers on the exhausts of small-diameter cyclones reduced dust emissions to the atmosphere by 22 to 35 percent while skimming 14 to 16 percent of the exhaust air. Increased skimming rates by forced induction was not effective in improving the performance of the involute skimmer because of a lowering of cyclone efficiency at elevated skimming rates. These studies indicated that an involute skimmer is of limited benefit for solving problems of high dust emission from cyclones. KEYWORDS: air pollution, cotton (*Gossypium*), cotton dust removal, cotton ginning, involute skimmers, pneumatic conveyors, small-diameter cyclones.

INTRODUCTION

Mechanical harvesting and accelerated harvesting and ginning rates have necessitated the installation of extensive trash-handling systems at modern cotton gins. A typical cotton gin in a stripper-harvesting area will handle up to 100 tons of gin trash per day. Pneumatic conveyance is the principal means of transporting gin trash from cleaners inside the gin plant to temporary storage facilities outside the gin. Small-diameter cyclones are generally used to separate gin trash from the high volumes of air utilized by the pneumatic conveying systems.

Small-diameter cyclones are highly efficient for collecting trash particles larger than about 20 μm (Wesley et al. 1972). For particles smaller than 20 μm, collection efficiency decreases as particle size decreases. Therefore, overall collection efficiency is a function of the size distribution of the gin trash. Baker and Stedronsky (1967) and Wesley et al. (1972) have reported overall collection efficiencies in excess of 99.9 percent for gin trash originating from both picked and stripped cotton. Although the percentage of trash escaping the cyclone and entering the atmosphere is small, the cumulative weight of emissions resulting from high processing rates can be large enough under some circumstances to create problems in meeting stringent air-quality standards.

Air being discharged from a cyclone flows upward in a helical vortex within the exhaust duct. Much of the dust in the discharge air is concentrated near the side wall of the exhaust duct. We thought it might be possible to skim off a small portion of the air near the wall of the duct and thus remove a substantial amount of dust from the exhaust air. Air and dust skimmed in this manner from the cyclone outlet would have to be separated before the air is discharged back to the atmosphere. However, because the volume of skimmed air would be small in comparison to the total exhaust volume, we felt that this approach might offer the most practical solution when a cyclone was exhausting too much dust to the atmosphere. This report describes experiments

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conducted over 3 yr to evaluate the performance of an involute skimmer incorporated into the exhaust duct of a small-diameter cyclone.

SKIMMER DESIGN

The skimmer consisted of an involute enclosure containing an annular skimming slot, a central discharge duct, and a tangential skimmer outlet (fig. 1). The involute skimmer was connected to the exhaust duct of a cyclone by means of a circular collar attached to the bottom of the involute enclosure. The central discharge duct of the skimmer protruded into the exhaust duct of the cyclone, forming an annular skimming slot around the circumference of the discharge duct. A small portion of the air flowing upward in the cyclone exhaust duct entered the skimming slot, and the remainder of the air was discharged to the atmosphere through the central discharge duct. The skimmed air was collected in the involute housing and discharged through the tangential outlet into a bag filter. Skimmer dimensions, given as a function of cyclone diameter, are shown in figure 2.

EQUIPMENT AND PROCEDURES

Two sizes of involute skimmers were evaluated in three separate experiments. In one experiment, we measured the performance of a skimmer sized for a 16-in-diameter cyclone, and in two other experiments we evaluated a skimmer sized for a 36-in-diameter cyclone. In all experiments, performance evaluations were based on dust-emission rates from the cyclone-skimmer system.

1975 Experiment

In this experiment, we evaluated a skimmer sized for a 16-in-diameter cyclone (fig. 3). The skimmer was designed to accommodate various sizes of cen-

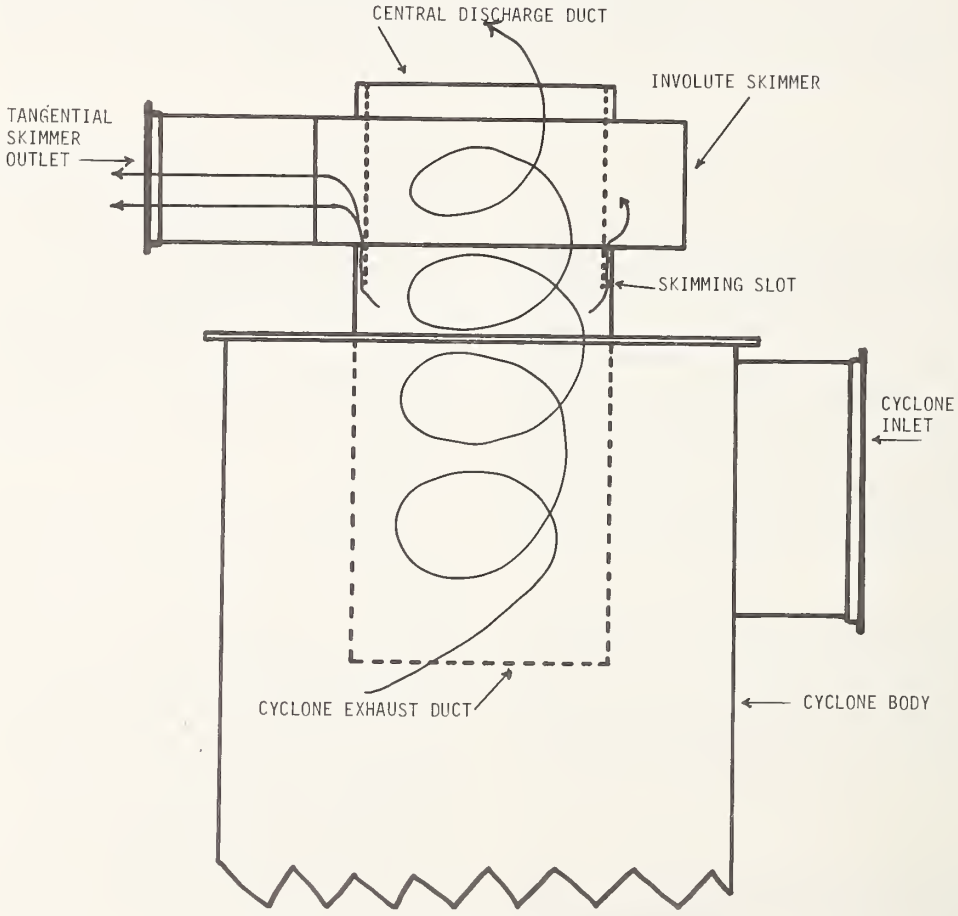

Figure 1.—Involute skimmer mounted on a cyclone.

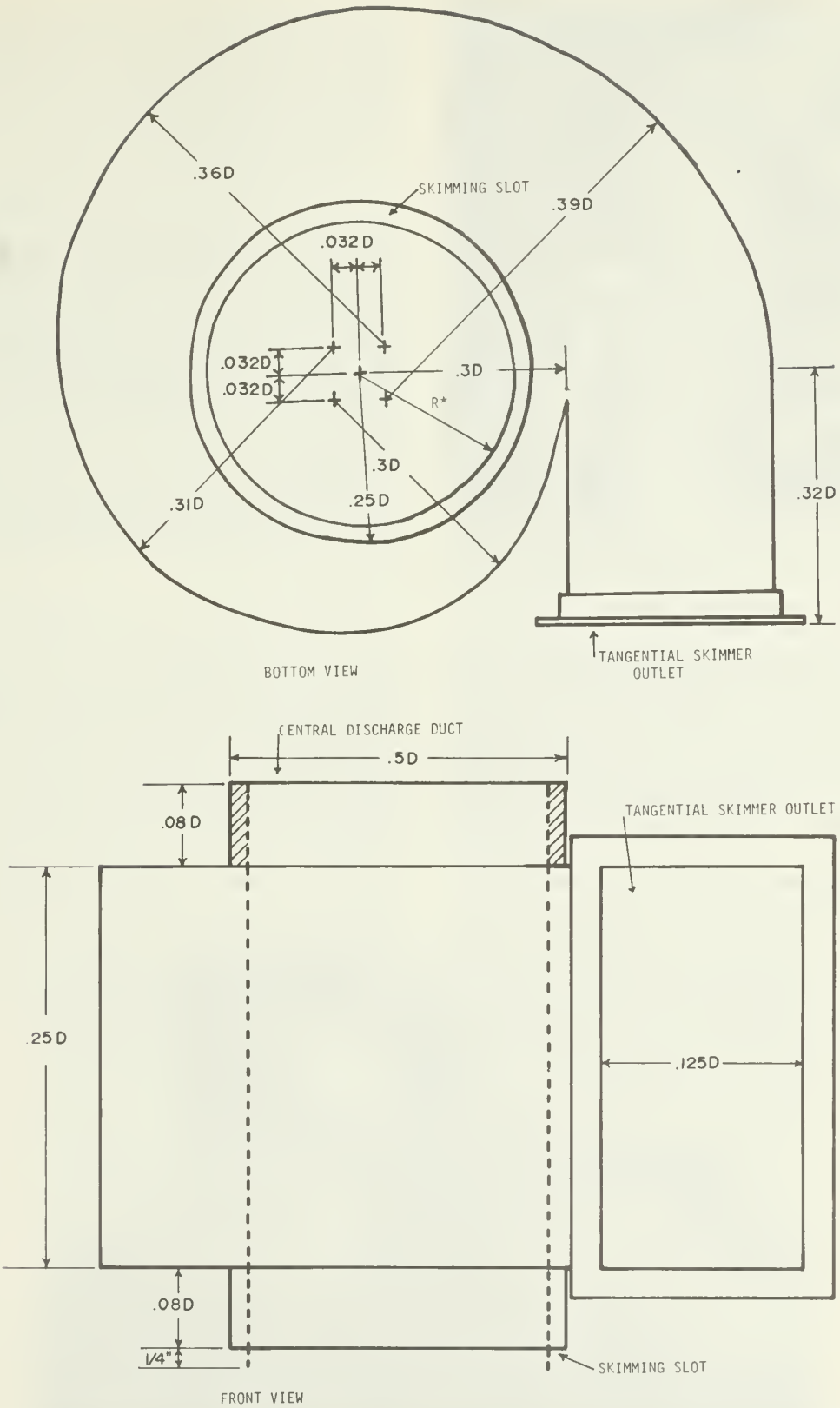

FIGURE 2.—Involute skimmer, dimensions as a function of cyclone diameter. *Note: This dimension is the radius required to give the desired skimming-slot width.

FIGURE 3.—Involute skimmer mounted on a 16-in-diameter cyclone.

tral discharge ducts. By using discharge ducts with diameters of 7½, 7¼, and 7 in, we were able to test skimming-slot widths of ¼, ⅜, and ½ in. Also, by using an 8-in-diameter discharge duct, we were able to close the skimming slot completely. This latter arrangement was analogous to operating a cyclone without a skimmer and served as the control in this experiment.

The skimmed portion of the cyclone exhaust entered the skimming slot solely as a result of natural vortical forces in the cyclone exhaust duct. A large filter bag attached to the skimmer outlet removed dust from the skimmed air. The filter bag was sized to provide a large cloth area to air volume ratio in order to limit back pressure to a low value.

A 19-in centrifugal fan delivered approximately 530 ft^3/min of air to the cyclone. Sifted gin trash was fed into the air-delivery system by an auger feeder at an average rate of 18.2 lb/min. The gin trash used in this experiment was obtained by sifting ordinary gin trash with a ¼- by ¼-in-mesh screen to remove large burs and sticks. A particle size distribution of the sifted material revealed that 20 percent of the particles were larger than 250 μm, 73 percent were between 45 and 250 μm, and 7 percent were smaller than 45 μm.

Dust-emission rates and air volumes were determined for each skimming slot size and the control. This experiment was replicated six times.

1976 EXPERIMENT

The skimmer investigated in this experiment was sized for a 36-in-diameter cyclone. The cyclone was handling separator and air-line cleaner trash from an unloading fan in a conventional ginning system for stripper harvested cotton (fig. 4). The cyclone was handling approximately 3,400 ft^3/min of air and 6 lb/min of gin trash consisting of dust, sand, small sticks, leaf particles, and lint fly.

The skimming slot was $^9/_{16}$ in wide and occupied 12 percent of the area of the cyclone exhaust duct.

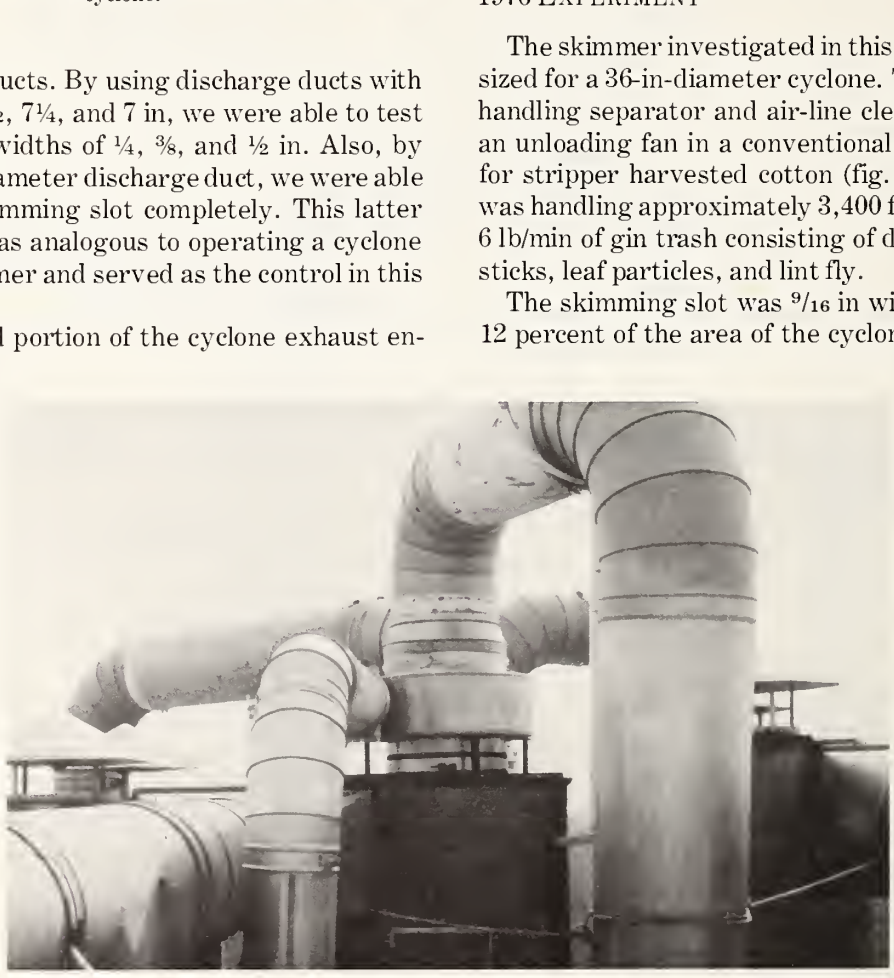

FIGURE 4.—Involute skimmer mounted on a 36-in-diameter cyclone.

The skimmed portion of the exhaust air entered the slot solely as a result of natural vortical forces in the cyclone exhaust duct. Dust-emission rates and air-exhaust volumes were determined from air samples collected during 17 separate periods of operation.

1977 Experiment

The skimmer and cyclone used in this experiment were the same as those used in the 1976 experiment. However, in this experiment additional air was induced into the skimming slot by means of a small exhaust fan connected to the tangential outlet of the skimmer. A slide value on the intake of the exhaust fan was adjustable to enable us to vary the amount of air skimmed from the cyclone exhaust duct. In this experiment, we evaluated three air-skimming rates: 19, 26, and 32 percent of the cyclone exhaust air. The experiment was replicated 10 times.

Sampling Methods and Data Analysis

In all experiments, air samples were taken from the central exhaust duct to determine dust-emission rates. Also, in two experiments (1976 and 1977), additional air samples were taken from the skimmer outlet. Air samples were collected isokinetically by means of a modified high-volume air sampler (Parnell and Baker 1973). The sampled air passed through a type A/E glass-fiber filter that collected the airborne dust and fly lint. Isokinetic conditions were maintained by using a variable-speed control on the air-sampler motor and by monitoring air velocities in the cyclone exhaust and air-sampling nozzle.

Exhaust emission rates were determined by the equation

$$E = \frac{SV}{vT} \quad (1)$$

where E=exhaust emissions (grains per minute, gr/min), S=emissions sample weight (grains, gr), V=total air volume of exhaust (cubic feet per minute, ft³/min), v=sampled air volume (cubic feet per minute, ft³/min), and T=time air was sampled (minutes, min).

All experiments were of the randomized complete-block design. Data were analyzed by analysis of variance, and differences between means were determined by Duncan's multiple-range tests.

RESULTS

1975 Experiment

The dust-emission rate from the central outlet duct averaged 94 gr/min for the control, and 65, 63, and 61 gr/min for the ¼-, ⅜-, and ½-in skimming slots (table 1). There were no statistically significant differences in dust-emission rate among the three skimming-slot widths. However, all three skimming slots produced lower dust-emission rates than the control (no slot). A comparison of the dust-emission rates resulting from use of the three skimming slots to that resulting from use of no skimming slot revealed that the involute skimmer reduced dust emissions to the atmosphere by 31 to 35 percent.

The area of the skimming slots used in this experiment represented 12 to 23 percent of the area of the cyclone discharge duct. The percentage of air skimmed from the cyclone exhaust ranged from 14 percent (¼-in slot) to 16 percent (½-in slot). Thus, the percentage of air skimmed did not increase proportionally to the increase in skimming-slot area. An examination of the ratios of the percentage of

Table 1.—Air-discharge volumes, dust-emission rates, and percentages of air and dust collected by the involute skimmer, 1975 experiment[1]

Skimming-slot width	Dust-emission rate from outlet duct (gr/min)	Percentage of dust skimmed[2]	Air-discharge volume (ft³/min)		Percentage of air skimmed
			Outlet duct	Skimmer duct	
Control (no slot)	94b	0	530a	0	0
¼-in slot	65a	31a	500b	80a	14a
⅜-in slot	63a	33a	480bc	85ab	15ab
½-in slot	61a	35a	460c	90b	16b

[1]All values are averages of 6 replications. Means followed by a different letter are significantly different at the 0.05 level of significance.

[2]Based on dust-emission rate of control.

dust skimmed to the percentage of air skimmed for the three sizes of skimming slots indicated no distinct advantage for any one slot. However, we preferred the ¼-in slot (12-percent area) to the others, because it collected about as much dust as the other sizes, but it did so at a lower air-skimming rate.

1976 Experiment

The dust-emission rate from the tangential outlet of the involute skimmer averaged 100 gr/min, and that from the central exhaust duct averaged 355 gr/min (table 2). The sum of these two rates equals the total dust-emission rate (455 gr/min) of the cyclone. Thus, the emission rate from the tangential skimmer outlet represented a 22-percent reduction in total emissions. Also, the involute skimmer collected 530 ft^3/min of air out of a total cyclone exhaust volume of 3,470 ft^3/min, or approximately 15 percent. In this experiment, the involute skimmer collected a lower percentage of dust than the skimmer in the 1975 experiment. This lower dust-collection rate probably resulted from differences in the dust-particle size distribution.

1977 Experiment

Dust-emission rates from the central discharge duct to the atmosphere ranged from 134 gr/min at a skimming rate of 19 percent to 96 gr/min at a 32-percent skimming rate. However, because of large variations in the test data, these differences between skimming rates were not statistically significant (table 3). Dust-emission rates from the tangential outlet of the involute skimmer increased significantly with increases in skimming rate. At the 19-percent skimming rate, dust emissions from the tangential outlet averaged 46 gr/min, and at the 32-percent skimming rate the emissions increased to 162 gr/min. Thus, increases in skimming rate increased dust removal by the involute skimmer but affected dust emissions to the atmosphere very little. This contradictory data may be explained, at least partially, by an examination of the total emission rates. The total emissions are the sum of the emissions from the central discharge duct and the tangential skimmer outlet and represent the total loss of dust by the cyclone. As can be seen in table 3, total dust emissions from the cyclone increased as the skimming rate increased. Apparently, the pulling of additional air into the skimming slot by the exhaust fan interfered with the operation of the cyclone and caused it to operate less efficiently at the higher skimming rates. This change in operation of the cyclone was also reflected in the decrease in back pressure of the cyclone at the elevated skimming rates.

Table 2.—Dust-emission rates and air volumes for the 1976 involute skimmer experiment[1]

Source	Dust-emission rate (gr/min)	Air volume (ft^3/min)
Tangential skimmer outlet	100	530
Central discharge duct	355	2,940
Total	455	3,470

[1]All values are the average of 17 replications.

Summary and Conclusions

Experiments were conducted to evaluate the performance of an involute skimmer incorporated into the exhaust duct of a small-diameter cyclone. Measurements were made to determine the amount of dust skimmed from the cyclone exhaust by a skimmer equipped with various sizes of skimming slots and by a skimmer operated to skim 15 to 32 percent of the cyclone exhaust air.

We found, in an experiment on an involute skim-

Table 3.—Dust-emission rates, air-discharge volumes, and cyclone back pressure for the 1977 involute skimmer experiment[1]

Skimming rate	Dust-emission rate[2] (gr/min)			Air-discharge volume (ft^3/min)		Cyclone back pressure ($in H_2O$)
	Central discharge duct	Tangential skimmer outlet	Total emissions	Central discharge duct	Tangential skimmer outlet	
19 percent	134a	46a	180a	2,730	650	4.4
26 percent	125a	80b	205a	2,530	880	4.3
32 percent	96a	162c	258b	2,310	1,080	4.2

[1]All values are the average of 10 replications.

[2]Means followed by a different letter are different at the 0.10 level of significance as determined by Duncan's multiple-range test.

mer sized for a 16-in-diameter cyclone, that skimming slots occupying 12 to 23 percent of the area of the cyclone exhaust duct reduced dust emissions to the atmosphere by about one-third while skimming 14 to 16 percent of the exhaust air. There were no significant differences in dust-emission rates for the various skimming slots investigated, but we preferred the smallest slot (12 percent of the exhaust duct area) because of its lower air-skimming rate. In other experiments, we tested an involute skimmer connected to a 36-in-diameter cyclone on a cotton gin unloading system. Under these conditions and with a 12-percent skimming area, the involute skimmer reduced dust emissions 22 percent while skimming 15 percent of the exhaust air. Also, when this skimmer was attached to a small exhaust fan and operated at an air-skimming rate of 19, 26, and 32 percent, we noted a decrease in cyclone efficiency with no significant improvement in dust-emission rate.

It was concluded that an involute skimmer is of limited benefit for solving the problem of high dust emissions from overloaded small-diameter cyclones. For the relatively small decrease in emissions obtained by using an involute skimmer, it would be necessary to use additional fans, piping, and high-efficiency collection devices for the skimmed air. It is doubtful that the limited benefits of such a system would justify the extra cost of the additional equipment.

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